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Advanced Television Systems Committee

Performance Assessment of the ATSC Transmission System, Equipment and Future Directions

Report of the ATSC Task Force on RF System Performance

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Executive Summary

This report summarizes the technical findings of the Task Force on RF System Performance, created to study RF transmission performance issues concerning equipment complying with the ATSC A/53 standard. The sections that follow report the group's findings in the following areas: introduction and summary of the controversy that led to the formation of the ATSC Task Force on RF System Performance (Section 1); summary of the original transmission system requirements, industry interpretations of those requirements and current broadcasters requirements (Section 2); assessment of DTV RF propagation channels (Section 3); consumer DTV antennas and ease of reception issues (Section 4); DTV link budgets and sources of degradation (Section 5); analysis of 8-VSB system performance data (Section 6) and potential future improvements (Section 7). The conclusions of the Task Force are presented in Section 8 and the Task Force's recommendations to the ATSC are presented in Section 9.

The Task Force finds that the A/53 DTV transmission system and newer generation 8-VSB receivers largely meet the goals of outdoor reception by fixed receivers with 30 foot antenna height, in accordance with the FCC DTV planning factors. The group finds evidence that the goal of DTV replication of NTSC service where NTSC video quality is of ITU-R grade 3 or higher is largely met.

The Task Force finds that indoor reception of DTV with set-top antennas may be a service mode available only to a minority of viewers in some television markets, primarily due to insufficient RF field strength. Further advances in DTV receiver design, particularly in reducing the "multipath C/N penalty," are expected to increase the percentages of outdoor and indoor sites that successfully receive DTV, but the group finds that expectations of widespread indoor reception are inconsistent with the DTV planning factors and link budget variables. The Task Force further concludes that reliable DTV service to receivers using fixed indoor antennas will be available over a wider area than to portable indoor receivers utilizing self-contained antennas. The group finds that reliable DTV service to pedestrian and mobile receivers poses a unique set of challenges that will be difficult to overcome in a single transmitter environment.

The Task Force recognizes that many aspects of the received signal quality are independent of the type of modulation employed. Most prominent of these are the antenna and RF propagation channel characteristics, which degrade RF signals in any transmission system. The importance of DTV link budgets and variables affecting link margin cannot be overstated. Broadcasters control some variables that affect link margin, such as transmitter antenna height and transmitter power up to the authorized maxima. Manufacturers control other variables, including transmitter linearity, receiver noise figure, receiver selectivity and dynamic range, and 8-VSB demodulation and equalization design choices. Consumers have, however, enormous influence on link margin through their selections of antenna type, mounting location and height, and antenna orientation.

The group understands that even transmitter and receiver hardware that is theoretically perfect and lossless in every respect will still be subject to transmission errors induced by thermal noise, and that a minimum carrier-to-noise (C/N) ratio necessary to achieve a suitably low bit error rate for DTV service must be delivered to the receiver. Clearly there will be some percentage of potential viewers who are unable to install an antenna and receiving system capable of providing the minimum C/N to overcome the "digital cliff" -- for example, those consumers who cannot achieve reliable indoor reception and are unable to install a rooftop antenna. The Task Force is unable to estimate how many potential viewers this may represent, nor how much different that number would be using theoretically perfect lossless equipment versus existing consumer equipment.

It is evident to the Task Force that to maximize the number of consumers capable of receiving DTV, the primary means by which link margin can be increased are: antenna and receiver improvements; increasing RF field strength throughout a DTV market -- either by using a more powerful single transmitter or by supplementing the high power transmitter with on-channel repeaters; and finally, by selecting a more favorable "digital cliff." This last method implies acceptance of a lower DTV transmission data rate, regardless of the modulation format used.

The principal recommendation of the Task Force to the Executive Committee is that the ATSC investigate enhancements to the DTV transmission system. The consensus of the group is that enhancements to the existing A/53 standard will more rapidly meet more of the requirements delineated in the Broadcasters' Requirements document [7] and provide more ubiquitous DTV services for American consumers than mere reliance on technological innovation of receivers based upon the existing A/53 standard. The group commends the ATSC Executive Committee for its prompt action in assigning this work to the T3/S9 specialist group. It is the expectation of the Task Force that the trade-offs of data rate vs. robustness for different types of DTV service will be revealed during the course of the T3/S9 activity.

The Task Force also recognizes the need for further testing and studies, and recommends development of criteria for definition, prediction and measurement of different levels of DTV service in various modes of reception.

In the area of multipath interference, substantial progress has been made by receiver manufacturers in improving the strength of echoes tolerated, the echo dynamics (Doppler shift) tolerated, the delay spread of post-echoes tolerated and in reducing the multipath C/N penalty of recent A/53-compliant receivers and demodulator chips, compared to first generation products.

7 Future 8-VSB Performance Improvements

7.1 Future 8-VSB Receiver Improvements Through "Technological Innovation"

This section discusses receiver improvements achievable simply through advancements in technology, without requiring changes to the A/53 standard. Each major receiver subsystem is considered.

7.1.1 DTV Tuners

Revision of channel allotments will eventually result in a fully occupied spectrum in the TV broadcasting bands. Until the transition to DTV broadcasting is completed, the spectrum will include NTSC transmissions at relatively high power levels compared to DTV transmissions. Thusfar, the only experience with a fully occupied spectrum has been in cablecasting, where the power levels of the channels are uniform and there are no interfering signals except for other TV signals. It is difficult to be certain just how much general improvement may be needed in tuner design so over-the-air transmissions will be satisfactorily received in the future. Techniques for making such general improvement are, however, already known to tuner designers.

A variety of DTV tuners currently exist in the market for OEMs of A/53 receivers. Some DTV tuners currently available utilize a double-conversion architecture to convert VHF or UHF channels to a first IF signal above the UHF reception band and then to a second IF signal having a 44 MHz center frequency. Plural-conversion tuners are less susceptible than single-conversion tuners to interference from signals in "taboo" channels, particularly those containing image frequencies of the channel selected for reception. This is important for achieving satisfactory reception with the revised channel allotments.

Some manufacturers offer single-conversion DTV tuners for converting directly to IF signal having a 44 MHz center frequency. They are less expensive to manufacture than plural-conversion tuners. Since a single-conversion tuner contains only one oscillator, typically it exhibits less phase noise than plural-conversion tuners.

Designing DTV tuners for off-the-air reception involves a series of compromises to achieve acceptable performance over a wide range of received signal strengths. These compromises are similar to those made in designing tuners for off-the-air NTSC reception. All DTV tuners must be capable of providing linear output signals with C/(N+I) in excess of the 15 dB threshold value that VSB-8 needs at the data slicer in order for a Gaussian channel to be successfully received. In the real world the reception channel is likely to be Ricean or Rayleigh in nature, so the DTV tuner must deliver linear output signals with substantially higher C/(N+I) in order to accommodate loss of C/N in the filtering used for channel equalization and multipath suppression. C/(N+I) as much 30 dB may be necessary for satisfactory reception of a Rayleigh channel. Such C/(N+) is achieved only when the RF signal is received with sufficient strength, but is not so strong as to overload the tuner.

Adjacent channel interference (ACI) is caused by a strong adjacent channel overloading an RF amplifier or mixer in the tuner. There are nearly 400 upper or lower first adjacent channels in the DTV allotments, increasing the likelihood that ACI will be a problem. Biasing of the initial stage in the tuner so as to minimize overloading by a strong adjacent channel is not optimal biasing for reducing noise figure, however. The noise figure in a DTV tuner designed for off-the-air reception is apt to be around 10 dB, not counting the effects of echoes or loss in a downlead from an outside antenna.

This is substantially higher than the noise figure of 2 dB or so for a RF amplifier specifically designed for receiving only weak signals. Experts in the group recommend that a low-noise-figure RF amplifier be used as an auxiliary pre-amplifier for a current DTV receiver, when signal strength is low. Inclusion of a signal strength indicator in future DTV receiver designs would facilitate detection of such circumstances. Another potential improvement is incorporation of means for the receiver to exert automatic control of a remotely located low-noise amplifier.

Tuner input impedance is an area in which significant improvements are possible. It has been anecdotally reported that prior to mid-2000 measurements of about a dozen receivers from different manufacturers revealed that most of the receivers had a poor return loss, only slightly greater than 10 dB, and many were even poorer, with less than 10 dB return loss. In most cases the reactive component was capacitive and was about half the magnitude of the real component. In most, but not all cases, the real component of the tuner impedance was closer to 50 ohms than to 75 ohms. It was reported that rarely was the impedance match optimal for the tuned channel and typically the best match was on a channel different than that to which the DTV set was tuned.

7.1.2 IF Processing

The IF processing includes all IF filtering and amplification from the first converter output of the tuner to the analog-to-digital converter (ADC) input. Typically, the IF filter that principally determines channel selectivity is a Surface Acoustic Wave (SAW) filter with a flat passband, a constant group delay within the passband, and a 3 dB bandwidth of approximately 6 MHz centered near 44 MHz. Some earlier DTV receiver designs establish the Nyquist roll-off by IF filtering with somewhat narrower bandwidth SAW filters. As compared to the SAW filter in an NTSC receiver, the SAW filter in a DTV receiver requires more fingers on both transducers to obtain the flatter passband and the steeper skirt slopes for similar adjacent channel suppression. This requires a larger substrate and packaging, so cost is somewhat higher. Current SAW filter designs can suppress triple transient echoes (TTE) about 50 dB with some 15dB insertion loss. Acoustic delay is around 1.5 microseconds, so TTE exhibits about 3 microseconds delay. TTE is well within equalization range and also is too low in amplitude to affect data slicing significantly.

The IF processing also includes fixed and variable gain amplifiers to (a) make up for the losses of the SAW filter and (b) provide Automatic Gain Control (AGC) at weak signal levels. In some designs, the IF signal from the IF processing is demodulated in the analog regime and the resulting baseband signal digitized by an analog-to-digital converter (ADC). In most newer designs, the IF signal is digitized by an ADC and is then demodulated in the digital regime. Preferably, the IF processing regulates the IF signal voltage so the full dynamic range of the ADC can be exploited and the full number of bits resolution available from the ADC is secured. For a modern ADC, this voltage is typically between 0.5 and 1.0 Vpp. Thus, the IF dynamic range requirements for DTV receivers differ little from those for NTSC receivers.

7.1.3 Analog-to-Digital Conversion (ADC) and Digital Demodulation

Most current designs for A/53 receivers to be sold in commerce utilize either 8-bit or 10-bit analog-to-digital converters, followed by purely digital demodulation of the 8-VSB signal to baseband I and Q components. The use of 10-bit-resolution ADCs allows more dynamic range for coping with multipath fading and ACI than 8-bit converters. The group recognizes that additional performance gains can be achieved using 12-bit or higher resolution ADCs, presuming these become economical for consumer receivers. The 12-phase trellis coding lends itself to polyphase analog-to-digital conversion, with an oversampling ADC in each phase to gain extra bits of resolution, reducing the quantizing noise.

Many recent designs for A/53 receivers employ bandpass subsampling of the 44 MHz IF. Beyond an increase in ADC precision, very little performance improvement may be necessary in the bandpass sampling and digital demodulation subsystems. The conversion of 8-VSB signals to double-sideband AM signals prior to demodulation, which suppresses quadrature-phase echoes and helps stabilize carrier synchronization loops, has recently come into use. The procedure may simplify some types of channel equalization.

7.1.4 Automatic Gain Control

Because of the importance of automatic gain control (AGC) to the proper operation of a DTV receiver, AGC is considered as a separate topic in this part of this document.

The AGC circuitry regulating gain in the analog portions of a DTV receiver typically encompasses the tuner, the IF processing and a portion of the demodulator. One purpose of such AGC circuitry is to assure that the full dynamic range of the analog-to-digital converter is exploited, to maximize the actual bit-resolution of the digitized DTV signal. Besides a DTV receiver having AGC circuitry regulating gain in its analog portions, the DTV receiver customarily has AGC circuitry regulating gain in its digital portions, so the equalized baseband DTV signal is scaled appropriately for data slicing. This is done to minimize the dynamic range required of digital multipliers employed in the equalizer.

Analysis of DTV field test data has revealed the need for rapid AGC response times to adapt to broadband ("flat") fading conditions. A closed-loop bandwidth of at least 75 Hz has been suggested for the AGC loop(s) in a home DTV receiver. A mobile receiver will require a higher closed-loop bandwidth, perhaps 200 Hz, in its AGC loop(s). Some manufacturers have indicated that their early prototypes had slower AGC, and that this limitation has been corrected in the latest model consumer receivers or those that will soon be on the market.

As in NTSC television receivers, it is customary to employ "delayed" AGC in DTV receivers. This technique must be carefully implemented for optimum receiver performance. Delayed AGC maintains the tuner at maximum gain, where it has the best noise figure, under weak signal conditions. As the input RF signal level increases above the minimum, all AGC is performed by the IF processing. When the IF processing gain approaches its minimum, the tuner gain is reduced to accommodate any further increase in RF input level. Accordingly, the tuner noise figure is degraded only when the signal is moderately strong and there is substantial C/N margin – i.e., at an operating point where the tuner noise figure is less important to receiver performance. The 'crossover' point at which the tuner takes over the AGC function from the IF processing must be selected not only for noise figure optimization, but also based on receiver overload (AM/AM nonlinearity) and cross-modulation considerations.

The preferred 'crossover' point for delayed AGC in a DTV receiver differs from 'crossover' point preferred in an NTSC receiver. In an NTSC receiver, keeping noise in the video more than 40 dB below average luma is subjectively more important than maintaining the best linearity of video signals, so the RF amplifier stage gain is cut back only when mixer overload is imminent. In a DTV receiver, linearity of the data modulation is critical to accurate data slicing. As long as the signal-to-noise ratio is maintained above threshold, the signal-to-noise requirements are less stringent than for an NTSC receiver. Accordingly, in a DTV receiver it is preferred to begin reduction of RF amplifier gain at a lower-strength input signal than is done in an NTSC receiver. This also reduces the likelihood of ACI in the DTV receiver.

Cross-modulation products may be generated in a mixer when strong adjacent or taboo channels are present and are excessively amplified. As an alternative to delayed AGC for DTV signals, the RF & IF sections may utilize separate AGC systems. In such designs, in order to prevent interfering signals being excessively amplified by the RF amplifier, so as to overload the mixer, the RF AGC is derived from the mixer output signal and is amplified wideband.

7.1.5 Carrier Synchronization

Many A/53 receivers rely to some extent upon the 8-VSB pilot for carrier synchronization, and some do not use it at all. Sole reliance upon the pilot is problematic for robust carrier synchronization in dynamic multipath channels with severe fading, since frequency-selective fades will sweep through the pilot frequency. Since most consumer receivers utilize fully digital processing techniques, pilot tracking loops are typically implemented on-chip with digital phase locked loops (DPLLs), rather than with external analog PLLs, as was done in early A/53 prototypes.

Improving carrier synchronization is the subject of substantial research by 8-VSB receiver designers and it is likely that some of the approaches being considered have not been disclosed to the industry at large. The group recognizes that carrier synchronization in multipath channels is a significant performance issue and that alternatives to purely pilot-based synchronization do exist and are reported to be used in some recent A/53 receiver designs. Besides pilot tracking loops, decision-directed techniques for suppressed carrier recovery, commonly used in QAM and QPSK systems, are well known. Some A/53 receivers now

use fractional equalizers or complex synchronous equalizers. These equalizers provide better tracking of the carrier than can be achieved using the real-only synchronous equalizers of early 8-VSB receiver designs.

Each method of carrier phase and frequency detection is theoretically subject to failure under certain multipath conditions, but a combination of techniques will reduce the likelihood of complete carrier synchronization failure in any particular real-world reception condition. The rapid changes in reception conditions that will be encountered by mobile receivers in fast-moving vehicles present particularly difficult challenges to maintaining carrier synchronization.

7.1.6 Symbol Timing Synchronization

Symbol timing synchronization, like carrier synchronization, is another area of active research by receiver manufacturers. Early A/53 receivers relied exclusively upon the Data Segment Synchronization (DSS) sequence, which is provided in the A/53 framing structure for this purpose. Newer receivers have either supplemented or replaced the DSS-based methods with band edge detection, spectral bright line detection or other techniques designed to improve timing synchronization robustness in the presence of dynamic multipath.

As in the case of carrier synchronization, each method of symbol timing phase and frequency detection is theoretically subject to failure under certain multipath conditions. However, a combination of techniques will reduce the likelihood of complete symbol timing synchronization failure in any particular real-world reception condition. The rapid changes in reception conditions that will be encountered by mobile receivers in fast-moving vehicles present particularly difficult challenges to maintaining symbol synchronization.

7.1.7 Adaptive Equalization

Several manufacturers have attempted to address severe Ricean (low K-factor) channels and Rayleigh faded channels, in the interest of improving indoor reception robustness in urban environments. By the end of 2000, several manufacturers had implemented adaptive equalizers that can cancel multipath echoes from 5-6 μs pre-echo delay to over 40 μs post-echo delay at amplitudes reaching 0 dB attenuation for single echoes at particular echo delays. They had also implemented a variety of equalizer algorithms which track echo dynamics out to 5-20 Hz, but with exponentially decreasing echo amplitude tolerance as echo dynamics increase in frequency. The benefits of these improvements relative to first generation receivers were clearly demonstrated in laboratory and field tests, but these improvements did not assure robust reception in some severe Ricean and Rayleigh channels that exist in the real world. Moreover, the positioning of the antenna was critical to maintaining satisfactory reception of DTV signals, presenting an ease-of-use issue in markets where not all DTV signals emanate from the same transmission antenna site.

Some members of the group suggested that the pre-echo range of adaptive equalizers should be increased. They thought this could be particularly important in ameliorating the critical antenna positioning sometimes necessary in Rayleigh faded channels, in which any echo may appear as the dominant path and echoes with arbitrary delays, up to the maximum echo delay spread, may appear as either pre-echoes or post-echoes. Longer pre-echo support will also extend the benefits of DOCR, as discussed in Section 6.

Besides increasing the ranges of pre-echo advance and post-echo delay that can be accommodated by A/53 receivers, designers now recognize that strong echoes, with amplitudes as large as or even slightly larger than the desired signal, must be tolerated to secure reception in many indoor reception environments. Laboratory data indicate that a single echo at or near 0 dB relative amplitude could be cancelled by some receivers available at end of year 2000, but these receivers are incapable of separating a useful principal signal from echo ensembles that include multiple strong echoes characteristic of Rayleigh channels. Solving the Rayleigh channel problem requires additional techniques not disclosed to the Task Force. Individual members of the group have asserted that the Rayleigh channel problem is solvable.

Some Task Force members have reported excellent simulation results for severe Ricean channels using Discrete Fourier Transform (DFT) techniques to measure echoes and to use these measurements for initializing the adaptive equalizer. In order to initialize or re-initialize adaptive equalizer filter coefficients,

these methods require measurements of the echo phases at times that known symbol sequences are transmitted. Reportedly, it is difficult to extract sufficiently accurate echo phase measurements from the existing Data Field Sync (DFS) reference signal for channels with echo delay spreads that are a large percentage of the DFS duration and it is impossible to extract this information for channels with echo delay spreads that exceed the duration of the DFS.

Receivers available in 2000 lock to and track the dominant path, and they re-acquire the channel if a previously undesired echo becomes the new dominant path. From a practical implementation viewpoint, it may be better for receivers to tolerate echoes greater than 0 dB and avoid re-locking during transient echo conditions. If, however, a signal weaker than the strongest one is chosen as the principal signal, the somewhat lower C/N of that principal signal is the best that will be achieved. The exact trade-offs are implementation issues for receiver manufacturers.

Manufacturers have also recognized that receiver capability to track higher-frequency echo dynamics is important for practical mobile reception. Additional industry experience with field testing and RF data captures will better define the requisite tracking frequency requirements and their statistical significance to determining broadcasting coverage. Existing 8-VSB equalizer designs show an exponential decrease in tolerable echo amplitude as a function of Doppler shift. Other techniques for tracking higher frequency dynamics are being developed, as indicated by the following simulation results of a next generation 8-VSB receiver chip[12]. After decaying from an echo tolerance of 0 dBc at 0 Hz to -3 dBc at 5 Hz, the receiver is able to tolerate a single 4 μs post-echo at -3dBc out to 40 Hz, with a very gradual decrease in echo amplitude tolerance out to 80 Hz.

From this and other data, including the group's understanding of multipath dynamics for fixed and portable receivers, some group members say that the issue of tracking time-varying echoes is largely solved for fixed and portable receivers in most environments. The group expects that tracking echo dynamics in DTV receivers in fast-moving vehicles during mobile reception will be more difficult. There is ongoing research on equalizing Rayleigh and severe Ricean channels. Methods to cope with the strong echoes, lower K-factors and higher frequency dynamics are sought which do not require inordinately high C/N ratios. The Task Force notes that the laboratory and field test data summarized in Section 6 and in the Appendices indicates C/N requirements in excess of 25 dB for some low K-factor channels that are in fact receivable by existing 8-VSB receivers.

Some simulations show that this extreme increase in required C/N is not inherent in the 8-VSB system, at least for static multipath channels, and noise enhancement can be avoided by directly calculating the equalizer coefficients based on correlating long blocks of data. Some group members share the opinion that a C/N requirement of 25 dB should suffice even with Doppler frequencies above 5 Hz for a single 0 dB echo. Sparse equalization is another technique that is being used to reduce noise enhancement. The group notes that the DTV Planning Factors make no allowance for C/N degradation caused by multipath.

Coping with higher-frequency dynamic multipath encountered in mobile reception will require integrated circuits considerably more complex than currently used in A/53 receivers.

7.1.8 Antennas with Electronically Steered Directional Sensitivity

There is current investigation into "smart" antennas that electronically combine the responses of two similar component antennas to achieve an overall directional antenna response that can be redirected subject to electrical control signals. These control signals will be supplied from a DTV receiver especially equipped to optimize the directionality of the overall antenna response. The receiver will perform the optimization based on a variety of data including AGC, C/(N+I), and equalizer tap weights. CEA has formed an R4 "WG4 Antenna/DTV Interface" committee to investigate and set voluntary standards for a DTV to "smart" antenna interface, as well as an R5 "Antenna" Committee considering "smart" antenna issues.

These "smart" antennas are expected to contribute to ease of reception of 8-VSB signals, especially in markets where DTV signals are received from different broadcast antenna locations. More rapid changes between channels received from different directions is possible. The directionality of a "smart" antenna could be adjusted automatically by the receiver or manually by remote control. The directionality of an

[12] NXT2002 simulated performance, provided by Nxtwave Communications

outdoor "smart" antenna can be changed almost instantly; there is no wait for the slewing of an electromechanical antenna rotor.

The responses of the two similar component antennas can be simultaneously combined in different ways to support concurrent reception of TV channels received from different directions. The concurrent reception can be by a single TV receiver with picture-in-picture capability or can be by different receivers in the household.

7.1.9 Antenna (Spatial) Diversity

Antenna or Spatial Diversity is a technique long used in digital communication systems to combat the effects of multipath interference, but which thusfar has not been used to any extent in DTV reception. A spatial diversity receiver employs two or more antennas, and two or more component receivers or significant portions of receivers. The antennas are positioned to be affected differently by multipath signals, so any notches in the frequency spectra of their respective responses can be filled in when they are combined with each other. The diversity receiver may simply select the best signal, or may intelligently combine the signals from two or more antennas prior to decoding.

To achieve sufficient de-correlation between the multipath characteristics "seen" by each antenna, the antennas usually are physically separated by at least one-quarter of the RF wavelength. Other ways of achieving spatial diversity are also being explored. Antenna diversity is most likely to be used in mobile applications. Insofar as portable receivers or fixed receivers with indoor or outdoor antennas are concerned, antenna diversity tends to be impractical for low VHF channels, but is quite manageable for UHF channels.

7.1.10 Polarization Diversity

Polarization diversity concerns the simultaneous transmission, reception, or both transmission and reception of a signal in two orthogonal RF polarizations. Such techniques have long been used to improve reception in various communication systems, and a transmission technique of this sort was proposed for DTV in a 1996 paper presented at the NAB Engineering Conference [23]. This paper reports that the frequency-selective fading caused by multipath is uncorrelated between the Vertical (V) and Horizontal (H) polarization components of a Circular Polarization (CP) wave. The multipath nulls in the H component are not at the same frequencies or depths as those in the V component. By using a CP receiver antenna, deep nulls in one polarization component are substantially filled in by the other polarization component of a received CP signal. Improvement in multipath fading was also observed using Elliptical Polarization (EP). The benefits of CP and EP were achieved without increasing transmitter output power in either case. The present FCC Rules do not prohibit CP or EP for DTV broadcasting.

One Task Force member has experimented with a pair of log-periodic indoor UHF antennas respectively arranged to receive H and V components of DTV signal transmissions. Although the transmitted DTV signal is horizontally polarized, de-polarization is caused by reflections — e.g., as occur when the signal passes through dense foliage. Nearly the same total power in the channel from the V as from the H antenna was observed at a number of sites where there is no line-of-sight path. When the H and V signals were combined in a simple passive power combiner, the gain ripple observed on a spectrum analyzer could be made much smaller than with just the H plane antenna response alone, despite the DTV signal being horizontally polarized when transmitted. It is speculated that CP or EP might benefit a receiver that experiences Rayleigh fading, since the vector combination of the independently faded H and V components may make Rayleigh channels more Ricean.

7.1.11 Changing Overall Receiver Layout

High VSWR in the downlead connection to the DTV receiver from an outside antenna raises the noise floor of the receiver, as well as reducing the signal power available to it. These effects significantly increase receiver noise figure (see Appendix E). It is difficult to optimize VSWR for different DTV signals with diverse channel frequency allocations, especially when the down-lead connection is driven directly from a wideband outside antenna designed to receive signals over as many as four octaves.

It has been proposed that the DTV receiver be reconfigured so front-end tuner and IF amplifier sections are located outdoors with the antenna connected directly to the front-end tuner through a balun, and the IF amplifier sections driving the downlead connected to a further IF amplifier section in the indoor receiver apparatus. The downlead is terminated in characteristic impedance for the IF signal, which prevents echoes in that connection no matter which DTV channel is selected for reception. A demodulator follows the further IF amplifier section in the indoor receiver apparatus. Channel-tuning remote-control signals are transmitted from the indoor receiver apparatus to the outdoor tuner. Frequency multiplexing can be used to transmit these remote-control signals and operating power to the outdoor tuner via the downlead.

In this proposal, plural outdoor tuners facilitate picture-in-picture (PIP) displays, receiving different displays on different monitors, or recording a channel other than the one currently being watched. The tuners are arranged to drive a shared down-lead connection with different-frequency IF signals. There is a reduction of the number of 6-MHz channels at which the down-lead connection must be terminated with its characteristic impedance in order to prevent echoes, compared to supplying the down-lead connection RF DTV signals that have not been converted in frequency. A lossy transmission line with the same characteristic impedance as the downlead is preferred for terminating the indoor end of the downlead over a broad band of frequencies. A high-input-impedance buffer amplifier with neutralization is preferred for extracting the IF signals from the indoor end of the downlead.

Reconfiguration of the DTV receiver to suit an outdoor antenna would create an additional class of DTV receiver than that used with an indoor antenna and does not help with problems of indoor antenna reception. Additional liability issues of weather-resistance, safety against lightning, proper installation, et cetera arise for the manufacturer of the outdoor tuner.

7.2 Future 8-VSB Receiver Improvements Through Changes to the A/53 Standard

The Task Force has discussed several proposals for enhancements to the A/53 standard. It is beyond the scope of this report to rigorously analyze the proposals. The T3/S9 committee has issued a Request For Proposals (RFP) for VSB enhancements and will evaluate the proposals in 2001.